Compact XYG-table fluid planar drive system for micro milling

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Abstract
In this paper, a compact XYG-table design for the manufacturing of micro parts is presented. The drive principle is based on the selective control of different air nozzles, whose fluid jets generate feed forces for planar motion. In combination with an aerostatic contactless guide and the according control system, very precise motion was achieved in an experimental test setup. Further investigations demonstrate the extension of the current system by an additional rotational degree of freedom.

1 Introduction
Currently for manufacturing of small workpieces with edge lengths in the range of a few micrometres to a few millimetres typically conventional, while precise, machine tools are used. As they are usually equipped with conventional drive and guide systems, they have not only disadvantageous workpiece to machine size ratios, but also are less energy efficient. Therefore, an innovative new XYG-table design for the application in desktop machine tools is presented in this paper.

2 Fluidic drive and guide principle
In the past, a fluidic XY-drive was developed [1]. The system mainly consists of a slide on the top and a machine frame on the bottom (Fig 1a). Pressurized air is streaming out of three vertical nozzles arranged at the frame. Thrust forces on the slide are generated by the deflecting these air jets at defined triangle profiles on the slide. A commutation algorithm for the drive nozzle units was implemented and allows defined movements in both directions. With the realised design, thrust forces up to 1 N at a flow rate of 170 l/min at 6 bar supply pressure could be provided in
both directions. The work area is 15 x 15 mm² with an overall size of 100 x 100 mm². With the table mass of 60 grams, linear table accelerations up to 15 ms⁻² and maximal velocity of 0.48 ms⁻¹ were achieved.

Figure 1: XY-table setup (a) with drive (b) and guide (c) principle

Prestressed air bearings for the active guidance of the slide are located in the corners of the system. A ceramic waver combines the air nozzles for the bearings and the gap measuring system, which is based on the capacitive principle, where the electrodes are directly sputtered on the waver surface. For the counter face, segments of electrical sheets have been mounted on the slide. In the air gap range between 0 and 25 µm, the standard deviation of the measurement noise is below 200 nm whereby a very high precision can be provided [1]. Circle trajectory tests with different radii and velocities showed a maximal control deviation of about 40 µm at a radius of 3 mm and an angular frequency of 3 Hz with a position sensor noise standard deviation of 1 µm. The reason for the deviation is the tilting of the bearing faces, which causes the loss of the air buffer in the bearings and leads to contact in the bearings. In order to investigate the suitability of the fluidic XY-table in micro milling operations, it was used as a workpiece table. A high speed spindle was engaged to enable appropriate cutting speeds with a tool diameter of 0.5 mm. A feed per tooth of 10 µm/tooth and a cutting depth of 5 µm have been chosen. Apart from the tilted alignment of the workpiece, the experiments demonstrated the general suitability for micro milling operations. Since the slide does not have any mechanical guidance, the dynamic
characteristic highly depends on the control. Currently, further investigations focus on the design and optimization of the control strategy.

3 Extension of the system by an additional degree of freedom

To increase the functional integration and to enable more complex milling operations, the XY-table is extended by a rotational degree of freedom. Although slight rotations are possible with the current XY-table (± 15°, centre position), design modifications are necessary to enable complete 360° rotations at any planar table position.

In order to maximize the thrust force, the angle of the triangle profiles was fixed to 45° (Fig 2a) and the space between two profiles was set according to analytical models and computational fluid dynamic (CFD) simulation results [2]. Additionally, the circular slide diameter was limited to 120 mm to achieve a compact design.

Figure 2: Extended XYC-table design

A number of dependencies determine the necessary number of drive nozzles to ensure feed forces in every slide position. On the one hand, an increasing number of drive profiles requires more drive nozzles. For cost reasons, the number of drive nozzles should not exceed twelve. With this specification, seven triangular drive profiles represent the maximum amount of profiles. On the other hand, a decreasing number of drive profiles leads to an increasing slide height, which limits the minimum number of triangular drive profiles. However, even with seven drive profiles, the height of the profile exceeds 25 mm (Fig 3b).

In order to improve the performance of the design, four triangle profiles were assumed. The derived principle (Fig 2b) has been kept and the triangle profiles were replaced by blade profiles (Fig 2c), forming four arrays. CFD analyses of the system show good results for the new profiles and a calculated thrust force up to 1.4 N at a pressure of 6 bar (Fig 3c). The blade profile geometry was optimized by CFD
simulations concerning shape (reduced slide height by 50%) and distance between the profiles in order to get maximum thrust forces and low force ripples.

4 Conclusion and outlook

In the first part, a functional compact planar drive system suitable for low force micro milling operations was shown and verified in an experimental test setup. In the second part, an extended design was presented, which enables rotations of 360°. Due to new improved drive profiles, the extended concept allows a very compact design even with a limited amount of drive nozzles. Further studies will concern the construction and testing of the new designed XYC-table and investigations will be extended to operations with liquid media. Finally, the system will be used with other modules for assembly of reconfigurable desktop machine tools [3].

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References: